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U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 134.
B. T. GALLOWAY, *Chief of Bureau.*

THE INFLUENCE OF A MIXTURE OF SOLUBLE SALTS, PRINCIPALLY SODIUM CHLORID, UPON THE LEAF STRUCTURE AND TRANSPIRATION OF WHEAT, OATS, AND BARLEY.

BY

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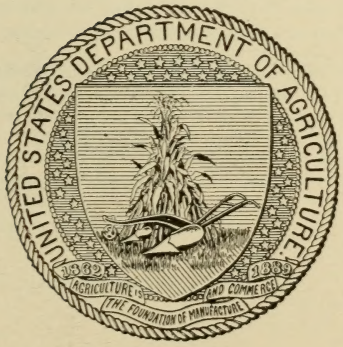
ISSUED AUGUST 20, 1908.



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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., May 27, 1908.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 134 of the series of this Bureau the accompanying technical paper entitled "The Influence of a Mixture of Soluble Salts, Principally Sodium Chlorid, upon the Leaf Structure and Transpiration of Wheat, Oats, and Barley," by Mr. L. L. Harter. This paper has been submitted with a view to publication by Mr. T. H. Kearney, Physiologist in Charge of Alkali and Drought Resistant Plant Breeding Investigations.

The investigations here described help to explain the physiological effects of alkali salts upon plants and hence to throw light upon the problem of what constitutes alkali resistance. The solution of this problem is of great importance in connection with the work of securing useful crop plants for growing in alkali soils.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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B. P. I.—369.

THE INFLUENCE OF A MIXTURE OF SOLUBLE SALTS, PRINCIPALLY SODIUM CHLORID, UPON THE LEAF STRUCTURE AND TRANSPIRATION OF WHEAT, OATS, AND BARLEY.

INTRODUCTION.

The investigation reported upon in the following pages was undertaken with a view to ascertaining whether the presence of a mixture of soluble salts, consisting chiefly of sodium chlorid, such as occurs in excessive quantities in many natural "alkali" soils, will affect the structure of plants not especially adapted to such soils, and if modifications of structure take place whether they resemble those which characterize plants growing naturally in saline soils (halophytic plants). The effect of this salt upon the transpiration of nonhalophytic plants was also studied.

It has been possible to demonstrate that culture in a soil containing considerable quantities of sodium chlorid together with other salts produces measurable changes in the leaf structure of wheat, oats, and barley and that these changes are in the direction of xerophytic and halophytic structure, i. e., that which characterizes plants that naturally inhabit very dry situations or saline soils. The most noticeable modification thus produced was the conspicuous bloom or waxy deposit that formed on the surface of the leaves. In control plants grown in nonsaline soil the bloom was so little developed as to be hardly observable. This development of bloom was accompanied by an easily measurable increase in the thickness of the cuticle and outer walls of the epidermal cells and by a marked decrease in their size.

In regard to transpiration, it was found that when the "alkali" salts are present in sufficient concentration to cause the modifications of structure above noted transpiration is considerably reduced. On the other hand, the same salts when present in amounts too small to produce any measurable influence upon structure have a decidedly stimulating effect upon transpiration.

It is believed that this line of investigation will throw much light upon the problem of what constitutes "alkali resistance" and will therefore be of service in the search for useful plants adapted to growing in saline or "alkali" soils.

EFFECT OF A MIXTURE OF SOLUBLE SALTS, PRINCIPALLY SODIUM CHLORID, ON PLANT STRUCTURE.

METHODS OF EXPERIMENTS.

Experiments to determine the influence of a mixture of salts in modifying the structure of plants were undertaken with wheat (*Triticum durum*), oats (*Avena sativa*), and barley (*Hordeum distichum*). The plants were grown in a greenhouse where the conditions as to light, heat, and moisture were fairly uniform. The seeds were germinated and the seedlings were grown for about four weeks in the soils with which the experiments were made.

The saline soil used was obtained from the vicinity of Salt Lake City, Utah,[a] and while it contained some sodium sulphate, sodium bicarbonate, and potassium sulphate, the results obtained are probably to be attributed chiefly to the action of sodium chlorid, since this is by far the most abundant salt present.

By mixing the saline soil with the requisite quantity of garden loam (from Washington, D. C.), the different concentrations of total soluble salts with which experiments were made (2 per cent, 1.5 per cent, and 1 per cent of the weight of the dry soil) were obtained, the percentages being calculated from the electrolytic resistance of the saturated soil.

On the basis of the analysis by the Bureau of Soils these three concentrations of total soluble salts would represent, respectively, 1.4, 1, and 0.7 per cent of sodium chlorid. These percentages are considerably above the limit which under natural field conditions is generally considered safe for wheat, oats, and barley. In fact, 0.5 per cent of sodium chlorid will usually prevent the production of seed in these plants.

In every case a check planting was made in the garden loam to serve as a control on the plants growing in the saline soil.

In order to prevent the leaching out of the salt in watering, the plants were grown in glass pots. These had a capacity of about 800 grams of the soil used. By careful watering, the salt was kept well distributed through the soil in the pot until the seeds had germinated and the plants had developed two or three leaves.

The effect of the salts on the structure of the plant was determined by sectioning the leaf and measuring the thickness of the cuticle and the size of the epidermal cells. All sections were made near the mid-

[a] An analysis by the Bureau of Soils, U. S. Department of Agriculture, of a sample of soil used in these experiments before mixing it with garden loam showed that it contained 2.1 per cent of soluble salts, of which 4.66 per cent was potassium sulphate, 16.98 per cent sodium sulphate, 70.58 per cent sodium chlorid, and 7.78 per cent sodium bicarbonate.

dle of the third leaf when the fourth leaf was about one-fifth the length of the leaf sectioned. Measurements were made of the thickness of the cuticle and outer wall (taken together) and also of the length and height of the cells of all epidermal cells in a transverse section between the third vein (counting the midrib as one) and the fourth vein on both the upper and the lower surfaces of the leaf. The filar micrometer was used in making the measurements.

The outer walls of the epidermal cells were measured together with the cuticle because in these young plants the latter is so thin that accurate measurements of the cuticle alone could not be made without the expenditure of a great amount of time. Careful preliminary measurements, however, were made of both the cuticle and the outer epidermal cell wall independently, the cuticle and cell wall being differentiated by staining with chloriodid of zinc. As a result it was found that the thickening had taken place chiefly in the cuticle and not in the cellulose zone of the cell wall. In the case of each plant species grown in each of the soils containing different concentrations of soluble salts as well as in the control soil, about 100 measurements of the cuticle and outer wall of the epidermal cells were made on both the upper and the lower leaf surfaces. Averages of the whole number of measurements are given in Table I.

In a similar manner measurements were made of the length and the height of the epidermal cells on both the upper and the lower leaf surfaces of each plant species grown in the soils containing different concentrations of soluble salts and in the controls. (Tables II and III.)

RESULTS OF EXPERIMENTS.

EFFECT ON THE FORMATION OF BLOOM.

The growth of the plants was retarded by the amount of soluble salts present. Wheat and oats made a slow growth in the soil containing 2 per cent of total salts (1.4 per cent sodium chlorid) and barley failed to germinate at this concentration. Seedlings of all three species grown in the soil containing 1.5 per cent of total salts (1 per cent of sodium chlorid) made a better growth, but were very weak. Seedlings grown in a soil containing 1 per cent total salts (0.7 per cent sodium chlorid) did fairly well, but were still decidedly inferior to the controls. Under natural conditions many agricultural plants, especially cereals, are unable to endure a soil content of more than 1 per cent of sodium chlorid, and even a considerably less amount will usually produce imperfect development.

Soon after the plants in the saline soils appeared above the surface of the soil they took on a dark bluish-green color, evidently due to

the presence of a coating of wax on the leaves,[a] while the control plants in every case retained their normal green color.

A comparison under the microscope of sections of leaves from plants grown in the saline soils with those of the controls showed that the waxy deposit on the cuticle was strongly developed in the former, but almost completely wanting in the latter. Bloom did appear, however, to some extent on the leaves of the control plants after the ground was allowed to become dry, indicating that the formation of bloom can be stimulated by a lack of water in the soil as well as by the presence of an excess of soluble salts.

The bloom was present in equal amount on both the upper and the lower surface of the leaf.[b] It appeared as a thin, almost homogeneous layer of waxlike substance which showed a slight tendency to accumulate along the lines of junction of the outer with the radial walls of the epidermal cells. A careful examination of the areas over the stomata[c] showed that there was no greater accumulation of bloom there than on any other portion of the leaf, the deposit of wax on the outer walls of the guard cells and the cells adjoining them being of uniform thickness with that overlying other cells.[d]

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[a] As to the origin of the bloom or wax on the leaves and stems of plants there are many theories, some of which were advanced as early as 1827. De Candolle asserted that the wax appears on the surface in the form of a liquid and is coagulated upon exposure to the air.

Karsten (Vegetationsorgane der Palmen) and Uloth (Ueber die Wachsbildung in Pflanzenreich, Flora, 1867, p. 422) sought to show that bloom originated through a complete chemical change of the cuticle and other cell wall layers. De Bary, on the other hand, contended that the bloom could not be the product of a modification of the cell wall, but that the wax is secreted by the epidermal cells themselves.

[b] Francis Darwin (On the Relation Between the "Bloom" on the Leaves and the Distribution of the Stomata. Journ. Linn. Soc. Bot., 22 : 99, 1886) found from a study of different species of Trifolium that there is a close relation between the distribution of the bloom and that of the stomata. When the bloom is on the upper surface of the leaf only, the average number of stomata on that surface (as compared with the lower) is twice as great as where both surfaces are covered with bloom.

[c] Wulff (Studien über verstopfte Spaltöffnungen, Oesterr. Bot. Ztschr., 48 : 201, 252, 298, 1898) made a study of the bloom on a large number of plants widely separated in relationship and found the stomata in many cases covered with wax. He states that while transpiration is largely reduced by means of the wax or bloom covering the stomata, assimilation still continues, and mentions in this connection Drimys, Elymus, *Papaver nudicaule*, and other plants.

Schleiden (Harmlose Bemerkungen über die Natur der Spaltöffnungen, Naturgesch., J. 4, bd. 1, pp. 56–59, 1838) noticed that the stomata of some species of the conifers were covered over with a wax, but does not mention Link, who observed the same condition earlier.

[d] De Bary (Ueber Wachsüberzüge der Epidermis, Bot. Ztg., J. 29, No. 9, p. 128; No. 10, p. 144; No. 11, p. 160, 1871) has made what is perhaps the most extensive study of the deposition of wax on the stem and leaves of plants that has ever been carried out. His observations include a large number of different species, as, for example, *Klopstockia cerifera*, *Panicum turgidum*, *Copernica cerifera*, and *Heliconia farinosa*. He found the wax to be in many cases more abundant on the guard cells and the cells adjoining them than on other portions of the leaf surface.

In view of the fact that Francis Darwin found the bloom in different species of *Trifolium* to be most strongly developed on the leaf surface having the greatest number of stomata, a count was made of the stomata on equal areas of both surfaces of the leaves of wheat, oats, and barley. In these cases the number of stomata as well as the amount of bloom was found to be about the same on both surfaces of the leaves.

EFFECT ON THE THICKNESS OF THE CUTICLE.

The following table shows the average thickness of the cuticle[a] and outer epidermal cell wall (taken together) of the upper and lower surface of the leaf of each of the different plant species grown in the soils containing various concentrations of soluble salts and in the control soils, the results of the measurements being expressed in microns.

TABLE I.—*Thickness of the cuticle and outer epidermal cell wall (taken together) of three species of plants grown in soils containing different concentrations of readily soluble salts.**

Plant.	Control (nonsaline soil).		Soil containing 1 per cent total salts (estimated 0.7 per cent sodium chlorid).		Soil containing 1.5 per cent total salts (estimated 1 per cent sodium chlorid).		Soil containing 2 per cent total salts (estimated 1.4 per cent sodium chlorid).	
	μ	μ	μ	μ	μ	μ	μ	μ
Wheat (*Triticum durum*)	2.6	2.7	3.2	3.0	3.2	3.2	3.3	3.3
Oats (*Avena sativa*)	2.4	2.2	3.0	3.0	3.2	3.3	3.2	3.2
Barley (*Hordeum distichum*)	2.5	2.4	3.0	3.0	3.2	3.3	.....	.....

*The figures represent in each case averages of about 100 measurements.

It will be seen from the above table that the thickness of the cuticle increases with the concentration of salt in the soil. In every case the thickness of the cuticle on both surfaces of the leaves is greater in plants grown in the soil containing an excess of soluble salts than in the control plants, and increases with the concentration of the total soluble salts present. The single exception to the latter rule was the lower leaf surface of the leaf of oats (*Avena sativa*) grown in soil containing 1.5 per cent of total salts, the average thickness of the cuticle having been in this case slightly greater than in the soil containing 2 per cent of total salts; but the difference is unimportant and is within the limits of experimental error.

In wheat, oats, and barley, so far as these experiments show, there seems to be little difference in the thickness of the cuticle between the upper and lower surfaces of the leaves, whether in soils containing an excess of readily soluble salts or in the nonsaline soils.

[a] All measurements of the thickness of the cuticle were made exclusive of the waxy deposit, which had been previously dissolved off by the addition of xylol.

EFFECT ON THE SIZE OF THE EPIDERMAL CELLS.

Table II gives the results of measurements, expressed in microns, of the average length and height of the epidermal cells of the upper leaf surface of three species of plants grown in soils containing different concentrations of soluble salts and of control plants grown in nonsaline soils.

TABLE II.—*Dimensions of epidermal cells of the upper leaf surface of different plant species grown in soils containing various concentrations of soluble salts.*[a]

Plant.	Control (nonsaline soil).		Soil containing 1 per cent total salts (estimated 0.7 per cent sodium chlorid).		Soil containing 1.5 per cent total salts (estimated 1 per cent sodium chlorid).		Soil containing 2 per cent total salts (estimated 1.4 per cent sodium chlorid).	
	Length.	Height.	Length.	Height.	Length.	Height.	Length.	Height.
	μ	μ	μ	μ	μ	μ	μ	μ
Wheat (*Triticum durum*)	50.5	50.9	29.8	26.0	40.3	34.1	29.4	26.0
Oats (*Avena sativa*)	41.9	33.2	34.3	30.6	31.4	29.5	36.8	27.5
Barley (*Hordeum distichum*)	44.6	37.2	37.5	34.3	30.8	36.3	.....	.....
Average	45.7	40.4	33.9	30.3	34.2	33.3	33.0	26.8

[a] The figures represent in each case averages of about 100 measurements.

Table III gives the results of measurements expressed in microns of the average length and height of epidermal cells of the lower leaf surface of three species of plants grown in soils containing different concentrations of soluble salts and of control plants grown in nonsaline soil.

TABLE III.—*Dimensions of epidermal cells of the lower leaf surface of different plant species grown in soils containing various concentrations of soluble salts.*[a]

Plant.	Control (nonsaline soil).		Soil containing 1 per cent total salts (estimated 0.7 per cent sodium chlorid).		Soil containing 1.5 per cent total salts (estimated 1 per cent sodium chlorid).		Soil containing 2 per cent total salts (estimated 1.4 per cent sodium chlorid).	
	Length.	Height.	Length.	Height.	Length.	Height.	Length.	Height.
	μ	μ	μ	μ	μ	μ	μ	μ
Wheat (*Triticum durum*)	47.4	48.4	31.9	33.2	34.9	32.3	30.8	24.1
Oats (*Avena sativa*)	45.0	37.2	32.3	33.3	30.4	30.6	27.9	25.4
Barley (*Hordeum distichum*)	44.2	44.9	36.2	37.1	36.5	42.2	.....	.....
Average	45.5	43.5	33.5	34.5	33.9	35.1	29.3	24.7

[a] The figures represent in each case averages of about 100 measurements.

It will be seen from Tables II and III that the leaves of the three plants grown in soils containing an excess of soluble salts have on an average smaller epidermal cells than those of the controls, the upper and lower leaf surfaces showing but little difference in this respect. Taking the average for all three species the length of the epidermal cells of the controls on both the upper and the lower surfaces of the leaf averages about 35 per cent greater than that of the epidermal

cells of the same plants grown in the soil containing 1 per cent total salts (estimated 0.7 per cent of sodium chlorid). The height (average for all three species) of the cells on the upper leaf surface of the control plants is about 33 per cent and that on the lower surface about 26 per cent greater than that of the plants grown in a soil containing 1 per cent of total salts.

A comparison of the height of the epidermal cells of plants grown in nonsaline soils and in soils containing 2 per cent of total salts (estimated 1.4 per cent of sodium chlorid) shows even more striking differences. The height of the epidermal cells on the upper leaf surfaces (average for all three species) is 51 per cent and on the lower surface 76 per cent greater in the control plants than in plants of the same species grown in a soil containing 2 per cent of total salts.

EFFECT OF A MIXTURE OF SOLUBLE SALTS, PRINCIPALLY SODIUM CHLORID, ON TRANSPIRATION.

EFFECT OF SALTS WHEN PRESENT IN SUFFICIENT QUANTITY TO PRODUCE BLOOM.

Wheat (*Triticum durum*) was germinated and grown in a natural saline soil containing 1.5 per cent of total soluble salts (estimated to contain 1 per cent of sodium chlorid), where the plants soon became covered with a copious bloom, and in a nonsaline soil as a control, where the bloom was inconspicuous. When the plants were about 6 inches high the leaves were detached and their cut surfaces were sealed by dipping in melted paraffin. They were then weighed at frequent intervals during a period of several hours, several leaves from the plants grown in saline soil being weighed together and several from the controls. All the leaves in each experiment were kept between weighings under uniform conditions as to heat, light, and moisture. The loss recorded at each weighing was taken as a measure of the amount of water transpired.

In the first experiment of this series the total initial weights of the leaves from plants grown in the saline soil and of those from the control plants were respectively 221 and 262 milligrams. After an exposure of twenty-one hours to the atmosphere of an ordinary room the weights were respectively 191 and 197 mg.: hence the leaves from plants grown in the saline soil lost 13.6 and those from the control plant 24.8 per cent of their original weights. An even greater difference was shown in a second experiment. In this the leaves from plants grown in the saline soil weighed at the beginning 377 mg. and the control 506 mg. The former lost 59 mg. and the latter 245 mg. in nineteen hours, or about 16 per cent and 48 per cent, respectively.

A third experiment in which the leaves were weighed at more frequent intervals gave results as follows, the weights being expressed in milligrams:

TABLE IV.—*Transpiration from leaves of plants grown in a saline and in a nonsaline soil as shown by the results of weighings at frequent intervals.*

Conditions of leaves and soil in which grown.	Weights at intervals of one-half to three-fourths hour.						
	12.45 p. m.	1.15 p. m.	1.45 p. m.	2.15 p. m.	2.45 p. m.	3.30 p. m.	4.15 p. m.
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
With bloom (grown in a soil containing 1.5 per cent of soluble salts)	281	276	272	272	270	268	267
Without bloom (control)	251	227	220	215	211	205	200

The leaves with bloom lost a total of 14 milligrams, or about 5 per cent of their original weight, while those without bloom lost 51 milligrams, or about 21 per cent of their original weight.

Whether the retardation of loss of water from the leaves of plants grown in soils containing considerable quantities of soluble salts when cut from the stems and exposed to the air is due to the presence of the bloom that develops on the leaf under these conditions or to the concentration of the cell sap, or to a combination of these factors, remains to be determined. The above-described results demonstrate, however, that leaves of wheat plants grown in saline soils containing as much as 1.5 per cent of salts lost considerably less moisture when cut off and allowed to dry than leaves of plants of the same species grown in a soil where no excess of salts was present but under similar conditions otherwise. Since in the former case, however, a relatively thick deposit of wax had developed upon the surface of the leaves, it is reasonable to assume that the presence of this bloom played some part in the decreased transpiration.[a]

[a] Sachs (Physiology of Plants) says: "The epidermis affords a protection against the excessive evaporation of the water from the leaves and young shoot-axes by means of the cuticle and the waxy coatings, which it is true do not absolutely prevent the evaporation of water from the epidermis cells, but render it exceedingly slow."

Reynolds (The Effect of Bloom on the Transpiration of Leaves. Bulletin No. 9, Oberlin College, 1898) found that the leaves of *Agave utahensis*, *A. verschaffelti*, *A.* sp., *Echevera peacockii*, and *Cotyledon* sp. from which the bloom had been removed lost about one-third more water than the same plants from which the bloom had not been removed. The results of Reynolds agree with those of Fr. Haberlandt (Wissensch praktische Untersuchungen auf dem Gebiete des Pflanzenbaues, 3: 156, 1877), who claims to have proved that the bloom on rape leaves is formed as a check upon transpiration, and with Garreau (Ann. d. Sci. Nat., 13: 322, 1849), who says that the removal of any waxy covering the leaf may possess favors transpiration.

EFFECT OF SALTS WHEN PRESENT IN AMOUNTS TOO SMALL TO PRODUCE BLOOM.

Wheat (*Triticum durum*) was also used in the experiments to determine the effect upon transpiration of a mixture of soluble salts, chiefly sodium chlorid, when present in the soil in quantities too small to produce any perceptible modification in the structure of the plants. As in previous experiments the seed was germinated and the seedlings were grown in the soils tested.

All plants were grown either in paraffined wire baskets or in glass jars, so that there was in no case any possibility of loss of water through the bottom or sides of the vessels. Five plants were grown in each vessel. Just previous to weighing, the pots were sealed over by means of paraffined paper, thus reducing to a minimum the possibility of loss of water except through the surface of the leaf.

The water lost by transpiration was determined by weighing the pots with the plants in them, the weighings being made at intervals of four to eight hours during the day for a period of two or three days. After the final weighing the area of the leaf surface was determined by making impressions of the leaves on solio photographic paper. The photographic paper was then weighed. The area of the leaf surface was then cut from the photographic paper and the remaining portion weighed. From the weight of the original photographic paper which was found by measurement to contain a certain number of square centimeters and the loss of weight after cutting out the impression made by the leaves, the actual area of the leaf surface could readily be calculated. The amount of water lost by transpiration could therefore be expressed in milligrams per square centimeter of leaf surface per hour—the unit which will be used in the discussion that follows.

Two series of experiments were conducted with wheat in natural soils containing, respectively, 0.09 and 0.12 per cent of total salts and estimated to contain, respectively, 0.06 and 0.08 per cent of sodium chlorid. These concentrations were obtained by thoroughly mixing the requisite quantity of garden loam with alkali soil obtained near Salt Lake City, Utah, the percentage of water-soluble salts present in the soil as thus made up being determined by means of the electrolytic bridge. The controls were grown in the pure garden loam. An examination of the plants grown in the alkali soils showed that the bloom was very slightly developed, probably not to a sufficient

degree to produce any material influence on the loss of water through the leaf.

The following table gives the amount of water transpired by wheat plants in soils containing these two concentrations of alkali salts and by the controls in each case, the amount of water transpired being expressed in milligrams per square centimeter of leaf surface per hour:

TABLE V.—*Amount of water transpired by wheat plants grown in soils containing different concentrations of soluble salts and by control plants grown in nonsaline soils.*

Series of experiments.	Control.	Soil containing 0.09 per cent total salts (estimated 0.06 per cent sodium chlorid).	Control.	Soil containing 0.12 per cent total salts (estimated 0.08 per cent sodium chlorid).
	mg.	*mg.*	*mg.*	*mg.*
No. 1	2.16	4.21	2.35	2.80
No. 2	3.27	3.98	3.01	3.35

The results show that transpiration is stimulated by the presence of amounts of soluble salts too small to produce any perceptible modification of structure. The stimulation was greatest in the soil containing the smaller amount of alkali, the amount of water transpired by the plants in the 0.09 per cent soil having been in the two series of experiments, respectively, 94 per cent and 21 per cent greater than in the corresponding controls, while in the 0.12 per cent soil it was only 19 per cent and 11 per cent greater.

GENERAL SIGNIFICANCE OF RESULTS.

It is not improbable and in fact these experiments seem to demonstrate that plants that are not halophytes when grown in saline soils undergo modifications of structure of a kind that are believed to reduce transpiration. It is a well-known fact that most xerophytes—i. e., plants growing naturally in dry situations—differ in many points of structure from mesophytes and hydrophytes (plants whose natural habitats are, respectively, moderately moist and very wet situations). Some of these characteristics of xerophytic plants, such as the reduction of the number of stomata, the situation of the latter in pits or furrows, the development of a covering of hairs on the leaf surface, etc., are doubtless efficacious in diminishing transpiration. Other means of protecting against excessive loss of water are thickening of the cuticle and its reenforcement by the secretion of wax or bloom which is deposited on its surface. Most halophytes (plants growing naturally in saline or "alkali" soils) exhibit similar peculiarities of structure.

The increased thickness of the cuticle and of the deposit of wax on the leaves observed in the experiments described in these pages can safely be attributed to the influence of an excess of soluble salts in the soil, since the presence of these salts in different concentrations or their absence was the only variant introduced. Pfeffer[a] is of the opinion that as a rule the cuticle is more strongly developed when there is a scarcity of soil moisture. But even under extremely arid climatic conditions, soils containing a large amount of soluble salts are usually in a moist condition. It is generally believed, however, that an excess of soluble salts in the soil will check the absorbing activity of the roots, thus creating a condition of "physiological drought."

In all the experiments, the results of which are summarized in Tables I, II, and III, the plants in saline soils and the controls grown in nonsaline soils were given an equal amount of water, yet the plants grown in saline soils modified their structure by depositing bloom on the leaf surface, by thickening the cuticle, and by reducing the size of the epidermal cells.[b] It would seem then that the plants in saline soils, although furnished an amount of soil moisture that was sufficient to produce a normal growth in the nonsaline soil, were actually subjected to xerophytic conditions. The explanation appears to be that the roots of the plants in saline soils were unable to take up moisture as readily as those in nonsaline soils, and the plants were therefore forced to modify their structure in the manner above described in order to reduce their transpiration.

So far as the results of these experiments can be regarded as conclusive, it may be said that when wheat plants are grown in a soil containing 0.7 to 1.4 per cent of sodium chlorid in addition to other salts the plants begin almost immediately after germination to take on xerophytic characters.

An indirect influence of the salt on transpiration is also shown (see Table IV), since the leaves of wheat plants grown in a soil containing 1.5 per cent total salts (1 per cent of sodium chlorid) lost considerably less water than the leaves of plants grown in nonsaline soils.[c] The decrease of transpiration from leaves of plants grown in saline soils when compared with those of the controls may be attributed to two factors: (1) The deposit of wax or bloom on the

[a] Physiology of Plants (Ewart's Translation), I: 239.

[b] Kissel (Der Bau des Gramineenhalmes unter dem Einflus verschiedener Düngung. Inaug. Diss. Giessen, 1906. Review in Bot. Centralbl., 109:403, 1908) found that phosphoric acid caused a thickening of the cell walls, and a diminution of the cell cavities in the stems of grasses. On the ôther hand nitrogen and lime induced a contrary effect. Results with potash were inconclusive as regards oats, but in the case of other grasses the effects were similar to those of nitrogen and lime.

[c] These results are in accord with those of Reynolds previously referred to.

leaf surface and the accompanying thickening of the cuticle and (2) increased concentration of the cell sap.[a]

The increased transpiration observed in wheat plants grown in soils containing an amount of soluble salts too small to cause any increase in the thickness of the cuticle or bring about any measurable deposition of wax is probably to be regarded as a result of chemical stimulation. It is well known that stimulation is effected by dilute solutions of many substances which at greater concentrations are toxic to plants. The writer[b] found that magnesium chlorid, magnesium sulphate, sodium sulphate, and sodium bicarbonate in water cultures stimulated the growth of wheat seedlings when present in dilutions too great to be toxic. Burgerstein,[c] who has made a very extensive study of the transpiration of plants under various conditions, finds that maize plants when subjected to solutions of 0.02, 0.10, and 0.25 per cent potash (K_2O) and soda (Na_2O) for a period of from one to four days exhibited a decreased transpiration as compared with control plants growing in distilled water. On the other hand maize plants grown during a period of forty-three to one hundred hours in solutions of 0.1, 0.25, 0.5, and 1 per cent of calcium nitrate and magnesium sulphate showed an increase of transpiration in the two weaker concentrations but a decrease in the two stronger concentrations. Burgerstein further finds that in very dilute solutions (0.05 to 0.25 per cent) of magnesium, of ammonium sulphate, and of calcium carbonate, transpiration as compared with that in distilled water increases with the concentration of the solution until a maximum is reached.

SUMMARY.

(1) Plants of wheat, oats, and barley grown from seeds in soils containing 1, 1.5, and 2 per cent of total salts (0.7, 1.0, and 1.4 per cent of sodium chlorid) very soon develop a pronounced waxy bloom upon the leaf surface and a thickening of the cuticle.

(2) The thickness of the cuticle increases with the concentration of the soil solution.

(3) The size of the epidermal cells decreases as the concentration of the salt in the soil increases, the epidermal cells of the plants grown in nonsaline soils being on an average the largest and those in the soils containing the greatest concentration of salts being the smallest.

[a] Sachs (Ueber den Einfluss der chemischen und physikalischen Beschaffenheit des Bodens auf die Transpiration der Pflanzen, Gessammelte Abhandlungen, 1: 417, 1892) states that transpiration from leaves may be reduced by the presence of materials dissolved in the water which the roots take up.

[b] The Variability of Wheat Varieties in Resistance to Toxic Salts, Bulletin 79, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1905, p. 42.

[c] Die Transpiration der Pflanzen. Eine Physiologische Monographie, 1904.

(4) When the amount of sodium chlorid present is much below the minimum concentration that is injurious under field conditions no perceptible modifications of the plant structure occur.

(5) Leaves of wheat detached from plants grown in nonsaline soil on which the bloom was not conspicuous lose by transpiration two to three times as much moisture in the same length of time as leaves from plants grown in a soil containing 1.5 per cent of total salts (about 1 per cent of sodium chlorid) and which possessed a marked development of bloom.

(6) Wheat plants grown in soils containing naturally 0.09 and 0.12 per cent of total salts (0.06 and 0.08 per cent of sodium chlorid) show an increased transpiration as compared with plants grown in a nonsaline soil. Of the two saline soils, that containing the smaller concentration of salts induced the heavier transpiration.

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